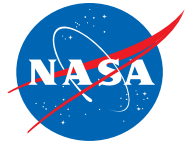


Reducing Conservatism in Aircraft Engine Response Using Conditionally Active Min-Max Limit Regulators

Ryan D. May

Vantage Partners, LLC

Sanjay Garg

NASA Glenn Research Center

4th Propulsion Control and Diagnostics Workshop
Ohio Aerospace Institute (OAI)
Cleveland , OH
December 11-12th, 2013

Overview

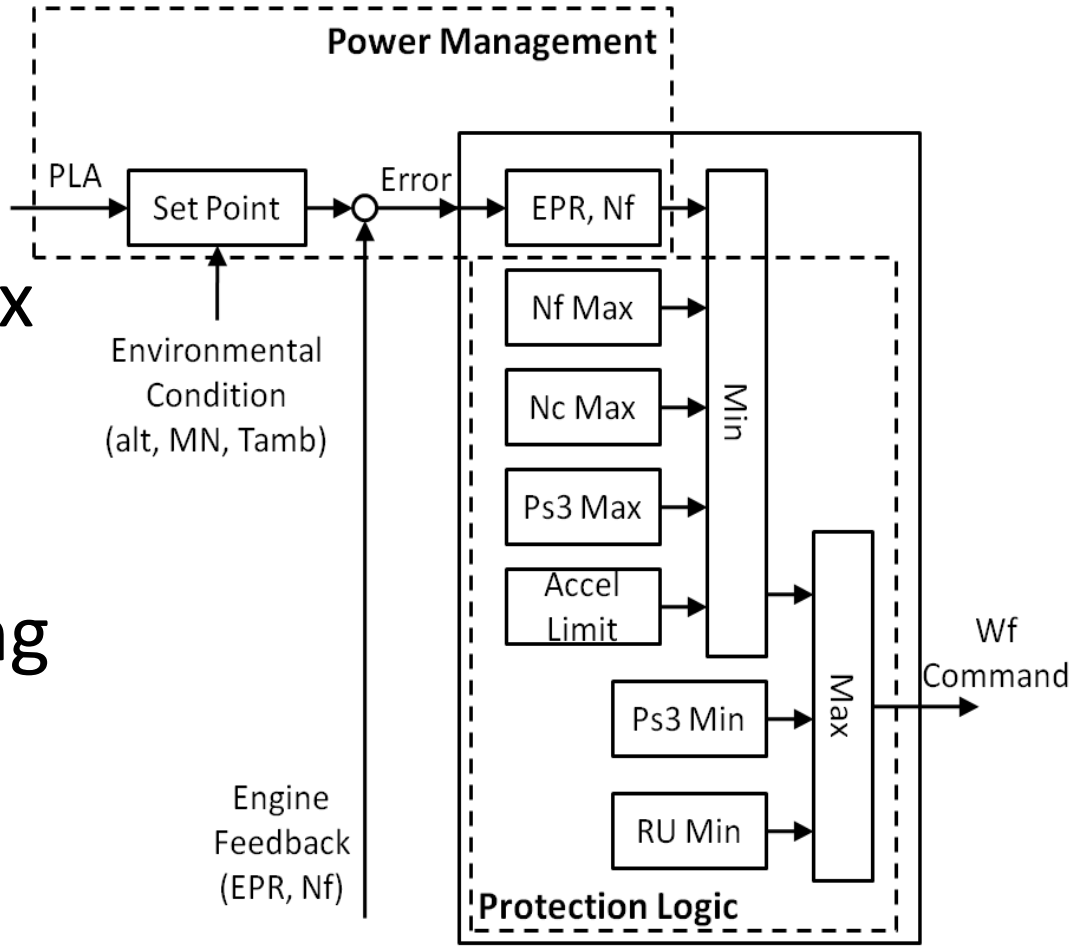
- Introduction
- Baseline Control Architecture
- Conditionally Active Limit Regulator Approach
- Simulation Examples
- Conclusions & Future Work

Introduction

- The primary task of an engine control system is to deliver the guaranteed performance while ensuring safe operation throughout operating envelope over the life of the engine
- Guaranteed performance is defined as meeting the FAA certification requirements for engine responsiveness – maximum allowed 95% rise time for idle to max thrust command

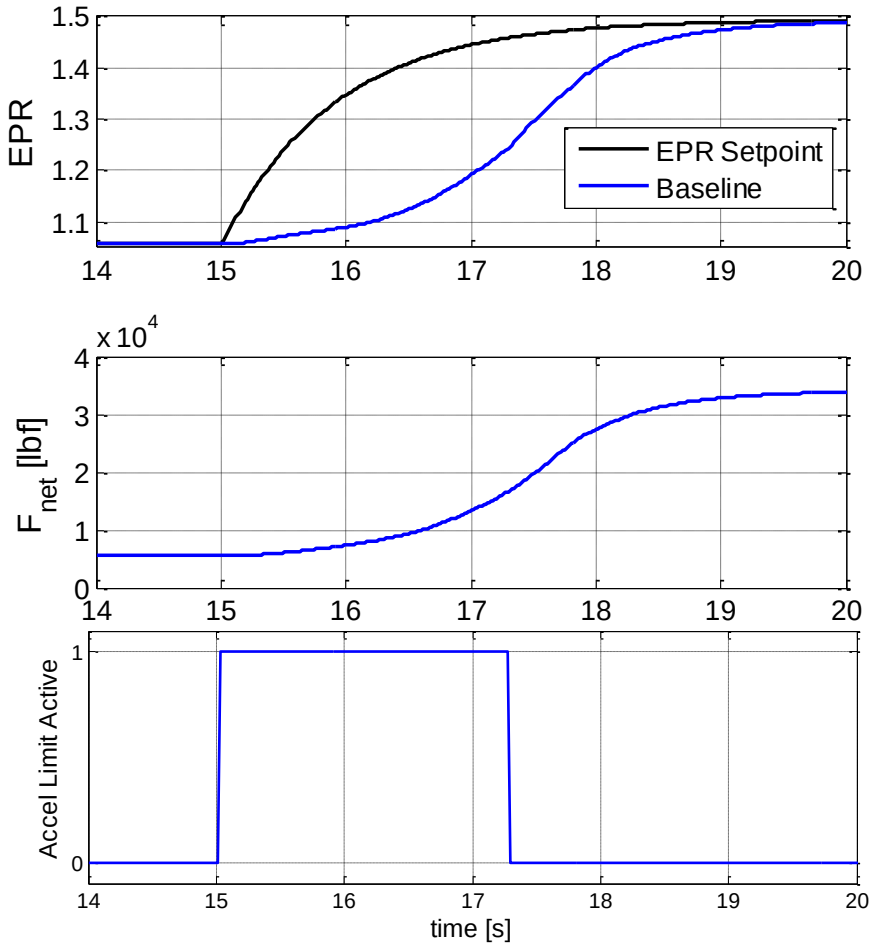
Baseline Control Architecture

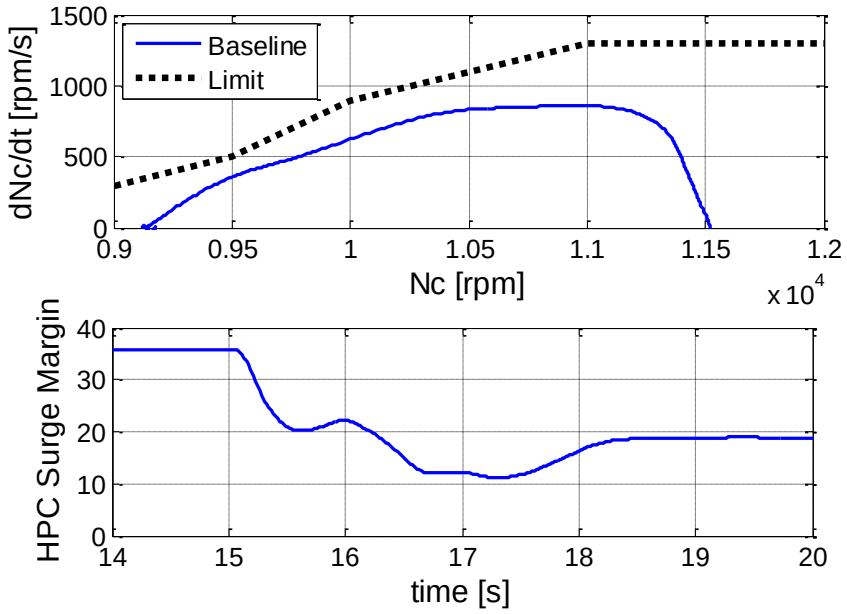
- Typical aircraft engine control is based on a Min-Max scheme
- Designed to keep the engine operating within prescribed mechanical and operational safety limits



Engine Response with Baseline Control

- C-MAPSS40k Full throttle burst at sea-level static conditions with an end-of-life engine





- Acceleration limit regulator is active immediately even though it is far from the limit - **Conservative Response**

Is the Conservative Response an issue?

- No:
  - Not during normal flight as long as it meets the FAA response requirements
- Yes:
  - On aircraft where primary flight control surfaces are damaged (e.g. UAL 232, Bagdad DHL, AA 587)
  - On aircraft with integrated flight/propulsion control
- Can we improve the engine response while maintaining the current architecture?

The Case for Conditionally Active Limit Regulators

- The baseline Min-Max selection control approach is inherently conservative
- Every limit regulator is capable of limiting fuel flow to engine – regardless of proximity to current limit
- Depending on how the individual PI regulators are tuned, the regulator may intervene when there is no danger of a limit being violated
- **To reduce conservatism, limit regulators should become active only when a limit is in "danger" of being violated.**

Conditionally Active Limit Regulators

- For operation with reduced conservatism while still ensuring safety, following two criteria must both be satisfied to enable a limit regulator:
  1) The regulated variable must be “close” to the specified limit
  2) The rate of change of the regulated variable is such that the regulated variable will reach the limit within a specified number of control update time steps

Conditionally Active Limit Regulators

- The conditions for the limit regulator to be active can be stated as:

For a maximum limit variable y_1 with limit y_{1max}:

$$y_1 \geq (1-\alpha_1) * y_{1\max}$$

$$y_1 + \frac{d}{dt} y_1 * \beta_1 * \Delta T \geq y_{1\max}$$

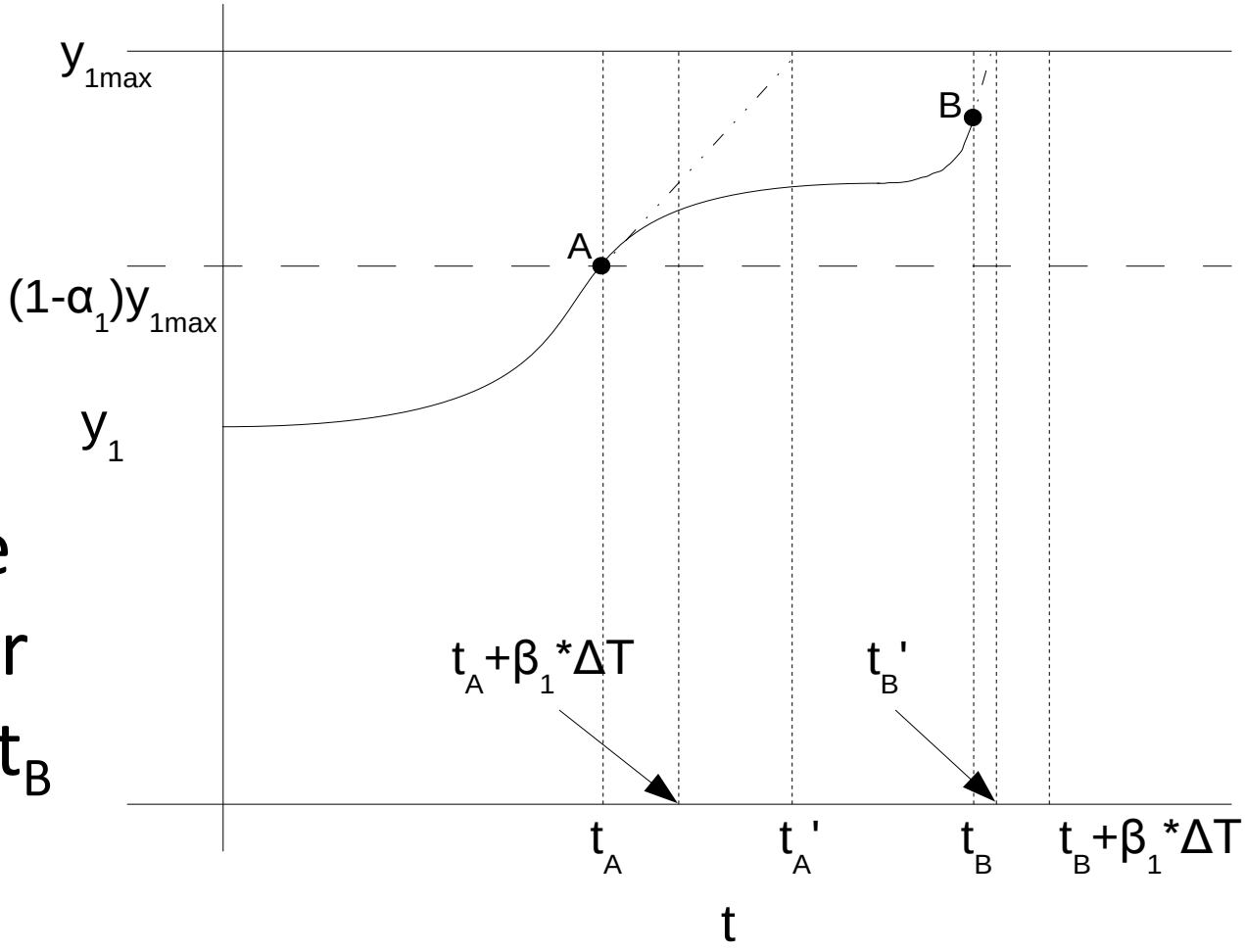
where α_1 and β_1 are positive design parameters

- Similar equations can be developed for minimum limit variables

Conditionally Active Limit Regulators

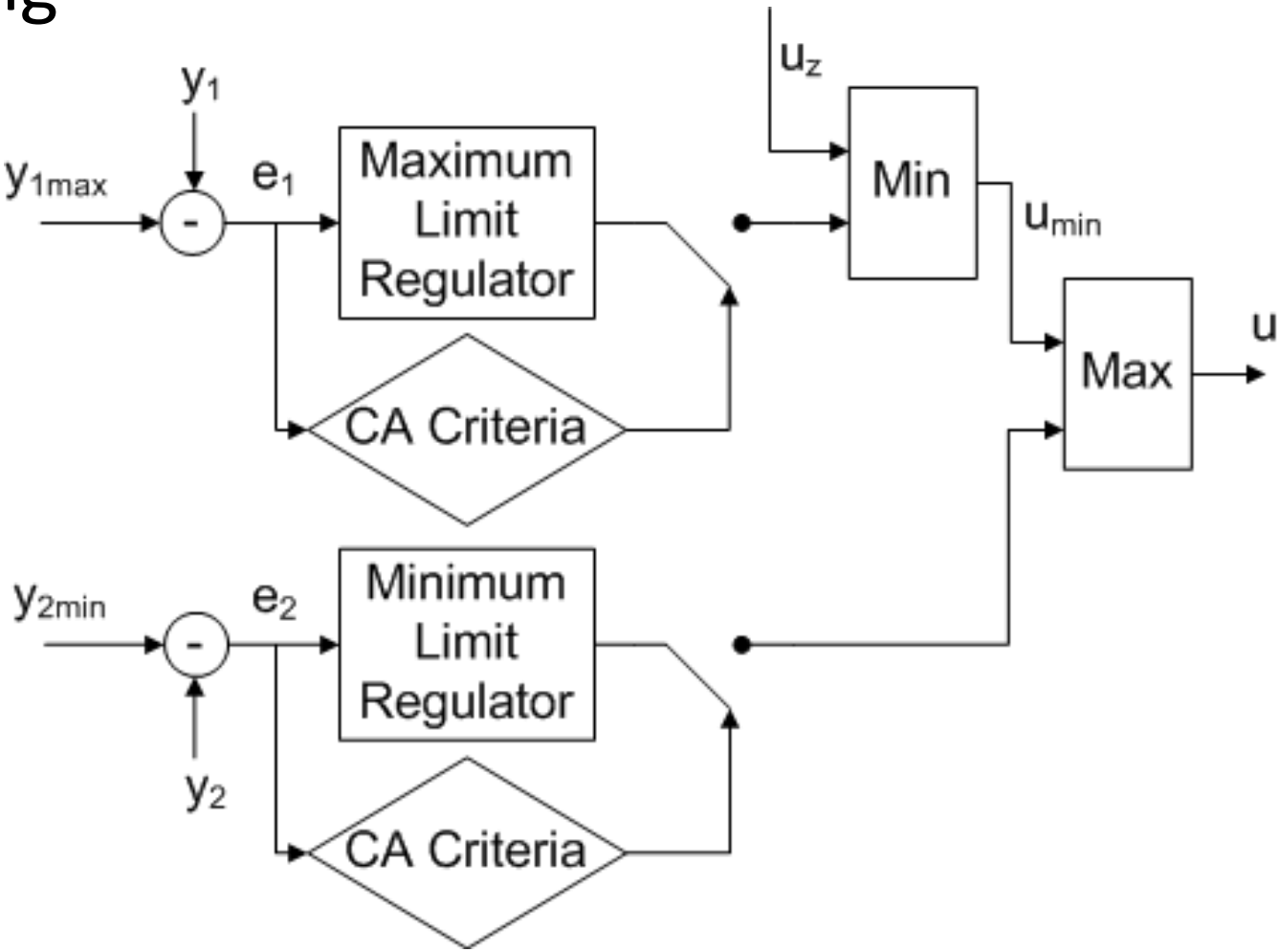
Graphical interpretation:

- Criteria 1 is satisfied at t_A
- Criteria 2 is satisfied at t_B
- Therefore the limit regulator is enabled at t_B



CA Architecture Modification

Uses the existing Min-Max architecture, but each regulator's output is only considered if the associated criteria are satisfied

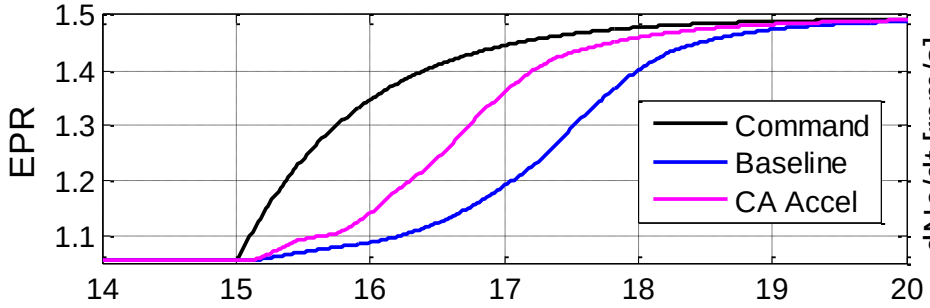


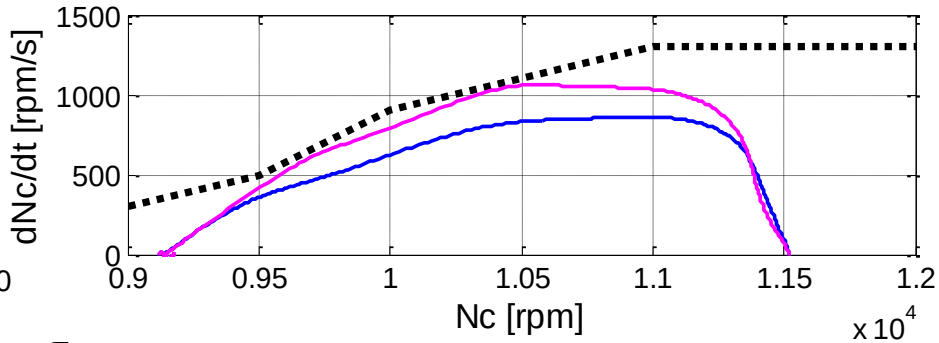
Choice of CA Design Parameters

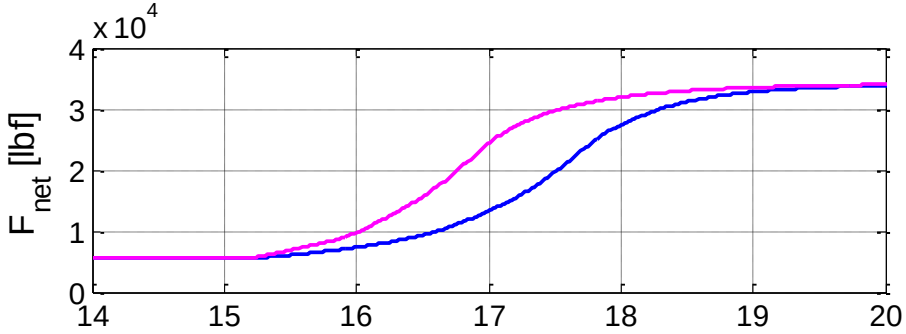
- We currently do not have an analytical approach to selecting the CA limit regulator design parameters α and β
- The CA parameters are tuned empirically
  - α value selected first to ensure limit is not violated for operation under worst case conditions
  - With a fixed α, the β value is selected to provide fastest possible response without violating limit
- Numerical optimization algorithm has been developed

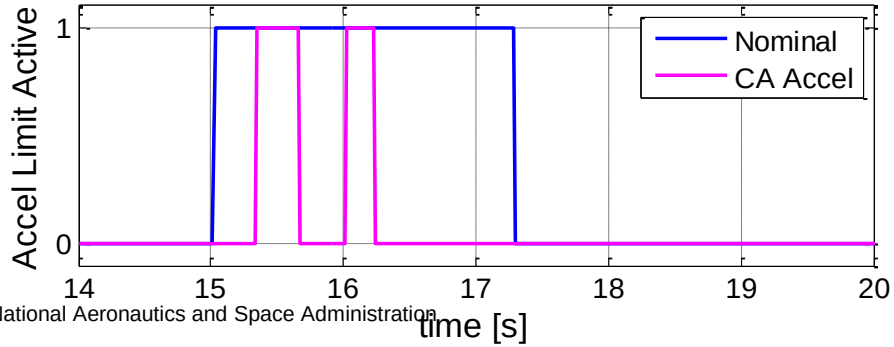
Simulation Results

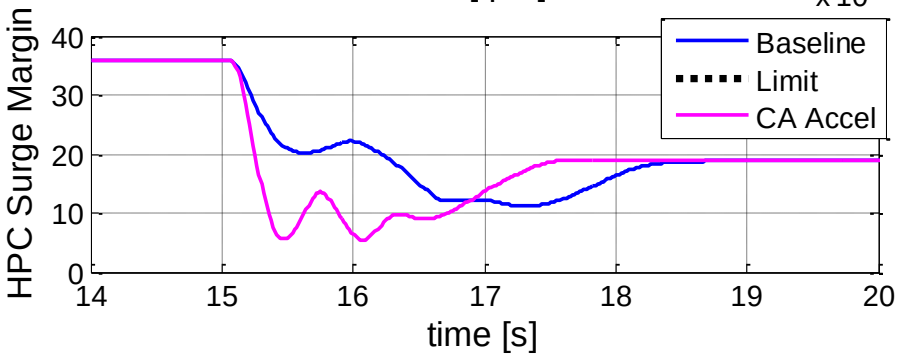
- Full throttle burst at sea-level static conditions with an end-of-life engine







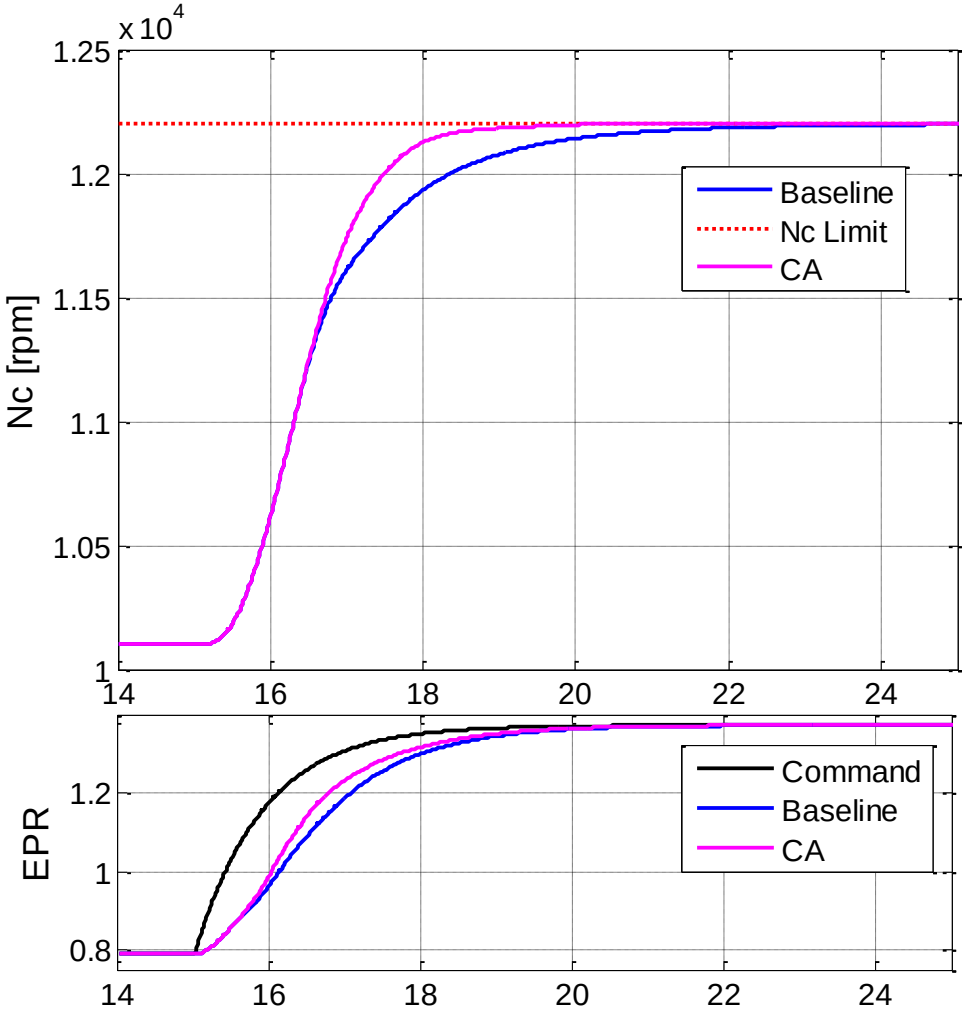


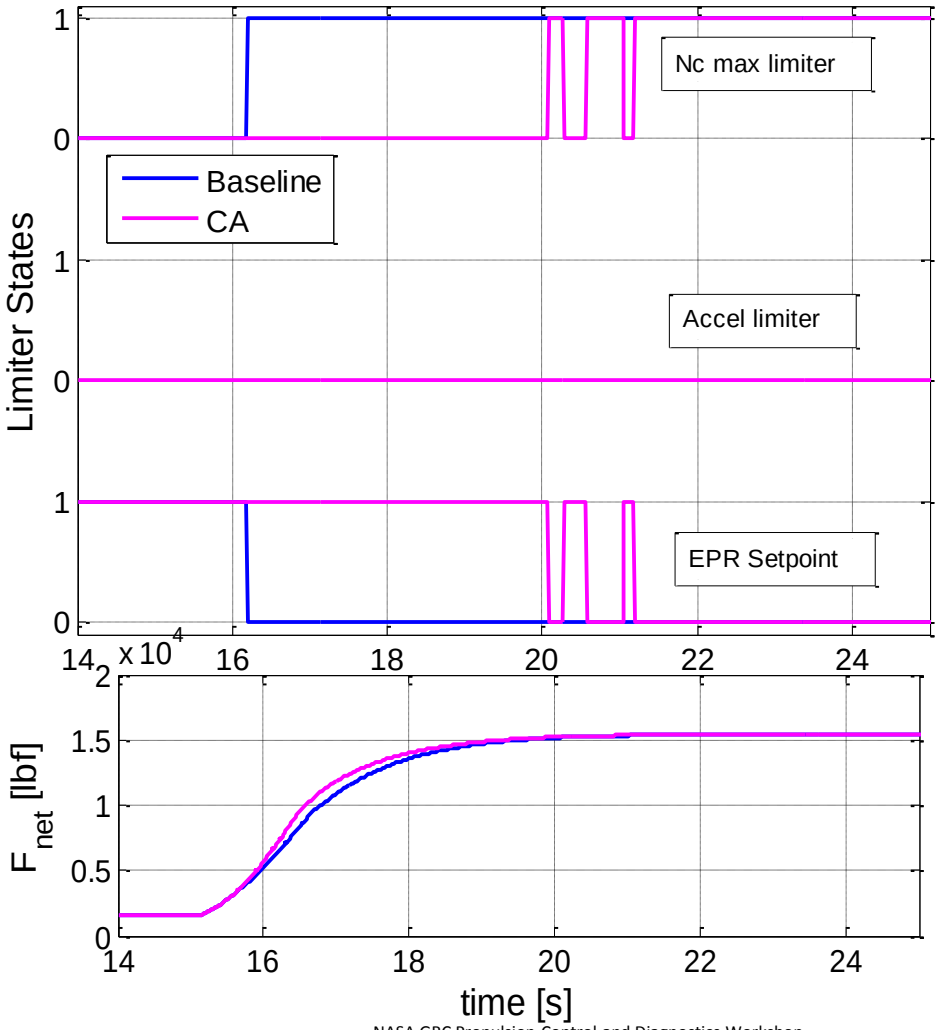


- Reduced conservatism resulting in much faster response

Simulation Results

- Case when a limit (Nc) is reached





Conclusions

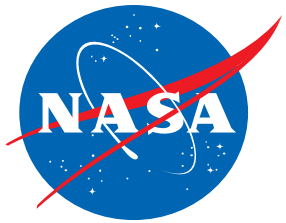
- The use of properly tuned Conditionally Active limit regulators can improve the engine response without compromising safety
- This approach should simplify the tuning and validation of the limit regulator gains as the regulators are only active in a small number of possible cases
- The CA limit regulator does not require modifications to any other aspect of the well established control architecture

Future Work

- Formulate the CA limit regulator approach in a proper mathematical framework
- Investigate development of analytical approach to determining the CA design parameters so as to satisfy performance and safety requirements

References

- May, R.D., Garg, S., "Reducing Conservatism in Aircraft Engine Response Using Conditionally Active Min-Max Limit Regulators," ASME-GT2012-70017, ASME Turbo Expo 2012, Copenhagen, Denmark, June, 2012.
- Nassirharand, A., “Optimization of conditionally active MIN-MAX limit regulators for reducing conservatism in aircraft engines,” Part of 2013 NASA Glenn Faculty Fellowship Program Final Report.


NASA